Radio spectrum

The **radio spectrum** is the part of the electromagnetic spectrum with frequencies from 3 Hz to 3,000 GHz (3 THz). Electromagnetic waves in this frequency range, called radio waves, are widely used in modern technology, particularly in telecommunication. To prevent interference between different users, the generation and transmission of radio waves is strictly regulated by national laws, coordinated by an international body, the International Telecommunication Union (ITU).[1]

Different parts of the radio spectrum are allocated by the ITU for different radio transmission technologies and applications; some 40 radiocommunication services are defined in the ITU's Radio Regulations (RR).[2] In some cases, parts of the radio spectrum are sold or licensed to operators of private radio transmission services (for example, cellular telephone operators or broadcast television stations). Ranges of allocated frequencies are often referred to by their provisioned use (for example, cellular spectrum or television spectrum).[3] Because it is a fixed resource which is in demand by an increasing number of users, the radio spectrum has become increasingly congested in recent decades, and the need to utilize it more effectively is driving modern telecommunications innovations such as trunked radio systems, spread spectrum, ultra-wideband, frequency reuse, dynamic spectrum management, frequency pooling, and cognitive radio.

Limits

The frequency boundaries of the radio spectrum are a matter of convention in physics and are somewhat arbitrary. Since radio waves are the lowest frequency category of electromagnetic waves, there is no lower limit to the frequency of radio waves.[4] Radio waves are defined by the ITU as: "electromagnetic waves of frequencies arbitrarily lower than 3000 GHz, propagated in space without artificial guide".[5] At the high frequency end the radio spectrum is bounded by the infrared band. The boundary between radio waves and infrared waves is defined at different frequencies in different scientific fields. The terahertz band, from 300 gigahertz to 3 terahertz, can be considered either as microwaves or infrared. It is the highest band categorized as radio waves by the International Telecommunication Union.[4] but spectroscopic scientists consider these frequencies part of the far infrared and mid infrared bands.

Because it is a fixed resource, the *practical* limits and basic physical considerations of the radio spectrum, the frequencies which are useful for radio communication, are determined by technological limitations which are impossible to overcome.[6] So although the radio spectrum is becoming increasingly congested, there is no possible way to add additional frequency bandwidth outside of that currently in use.[6] The lowest frequencies used for radio communication are limited by the increasing size of transmitting antennas required.[6] The size of

antenna required to radiate radio power efficiently increases in proportion to wavelength or inversely with frequency. Below about 10 kHz (a wavelength of 30 km), elevated wire antennas kilometers in diameter are required, so very few radio systems use frequencies below this. A second limit is the decreasing bandwidth available at low frequencies, which limits the data rate that can be transmitted.[6] Below about 30 kHz, audio modulation is impractical and only slow baud rate data communication is used. The lowest frequencies that have been used for radio communication are around 80 Hz, in ELF submarine communications systems built by a few nations' navies to communicate with their submerged submarines hundreds of meters underwater. These employ huge ground dipole antennas 20–60 km long excited by megawatts of transmitter power, and transmit data at an extremely slow rate of about 1 bit per minute (17 millibits per second, or about 5 minutes per character).

The highest frequencies useful for radio communication are limited by the absorption of microwave energy by the atmosphere.[6] As frequency increases above 30 GHz (the beginning of the millimeter wave band), atmospheric gases absorb increasing amounts of power, so the power in a beam of radio waves decreases exponentially with distance from the transmitting antenna. At 30 GHz, useful communication is limited to about 1 km, but as frequency increases the range at which the waves can be received decreases. In the terahertz band above 300 GHz, the radio waves are attenuated to zero within a few meters due to the absorption of electromagnetic radiation by the atmosphere (mainly due to ozone, water vapor and carbon dioxide), which is so great that it is essentially opaque to electromagnetic emissions, until it becomes transparent again near the near-infrared and optical window frequency ranges.[7][8]

Bands

A **radio band** is a small frequency band (a contiguous section of the range of the radio spectrum) in which channels are usually used or set aside for the same purpose. To prevent interference and allow for efficient use of the radio spectrum, similar services are allocated in bands. For example, broadcasting, mobile radio, or navigation devices, will be allocated in non-overlapping ranges of frequencies.

Band plan

For each radio band, the ITU has a **band plan** (or **frequency plan**) which dictates how it is to be used and shared, to avoid interference and to set protocol for the compatibility of transmitters and receivers.[9]

Each frequency plan defines the frequency range to be included, how channels are to be defined, and what will be carried on those channels. Typical definitions set forth in a frequency plan are:

- numbering scheme – which channel numbers or letters (if any) will be assigned
- center frequencies – how far apart the carrier wave for each channel will be
- bandwidth and/or deviation – how wide each channel will be
- spectral mask – how extraneous signals will be attenuated by frequency
- modulation – what type will be used or are permissible
- content – what types of information are allowed, such as audio or video, analog or digital
- licensing – what the procedure will be to obtain a broadcast license

ITU

The actual authorized frequency bands are defined by the ITU[10] and the local regulating agencies like the US Federal Communications Commission (FCC) [11] and voluntary best practices help avoid interference.[12]

As a matter of convention, the ITU divides the radio spectrum into 12 bands, each beginning at a wavelength which is a power of ten (10^n) metres, with corresponding frequency of $3\times10^{8-n}$ hertz, and each covering a decade of frequency or wavelength. Each of these bands has a traditional name. For example, the term *high frequency* (HF) designates the wavelength range from 100 to 10 metres, corresponding to a frequency range of 3 to 30 MHz. This is just a symbol and is not related to allocation; the ITU further divides each band into subbands allocated to different services. Above 300 GHz, the absorption of electromagnetic radiation by Earth's atmosphere is so great that the atmosphere is effectively opaque, until it becomes transparent again in the near-infrared and optical window frequency ranges.

These *ITU radio bands* are defined in the ITU Radio Regulations. Article 2, provision No. 2.1 states that "the radio spectrum shall be subdivided into nine frequency bands, which shall be designated by progressive whole numbers in accordance with the following table".[13]

The table originated with a recommendation of the fourth CCIR meeting, held in Bucharest in 1937, and was approved by the International Radio Conference held at Atlantic City, NJ in 1947. The idea to give each band a number, in which the number is the logarithm of the approximate geometric mean of the upper and lower band limits in Hz, originated with B. C. Fleming-Williams, who suggested it in a letter to the editor of *Wireless Engineer* in 1942. For example, the approximate geometric mean of band 7 is 10 MHz, or 10^7 Hz.[14]

The band name "tremendously low frequency" (TLF) has been used for frequency and wavelength of 1–3 Hz | 300,000–100,000 km (1000 Mm),[15] but the term has not been defined by the ITU.[16]

Band name	Abbreviation	ITU band number	Frequency and wavelength	Example uses
Extremely low frequency	ELF	1	3–30 Hz 100,000–10,000 km (100 Mm)	Communication with submarines
Super low frequency	SLF	2	30–300 Hz 10,000–1,000 km (10 Mm)	Communication with submarines
Ultra low frequency	ULF	3	300–3,000 Hz 1,000–100 km (1 Mm)	Communication with submarines, communication within mines, landline telephony, fax machines, fiber-optic communication
Very low frequency	VLF	4	3–30 kHz 100–10 km	Navigation, time signals, communication with submarines, landline telephony, wireless heart rate monitors, geophysics
Low frequency	LF	5	30–300 kHz 10–1 km	Navigation, time signals, AM longwave broadcasting (Europe and parts of Asia), RFID, amateur radio.
Medium frequency	MF	6	300–3,000 kHz 1,000–100 m	AM (medium wave) broadcasts, amateur radio, avalanche beacons, magnetic resonance imaging, positron emission tomography, electrical telegraph, wireless telegraphy, radioteletype, dial-up internet.
High frequency	HF	7	3–30 MHz 100–10 m	Shortwave broadcasts, citizens band radio, amateur radio, over-the-horizon aviation communications, RFID, over-the-horizon radar, automatic link establishment (ALE) / near-vertical incidence skywave (NVIS) radio communications, marine and mobile radio telephony, CT scan, magnetic resonance imaging, positron emission tomography, ultrasound, cordless phones.
Very high frequency	VHF	8	30–300 MHz 10–1 m	FM broadcasts, television broadcasts, cable television broadcasting, radars, line-of-sight ground-to-aircraft communications, aircraft-to-aircraft communications, emergency locator beacon homing signal, radioteletype, land mobile and maritime mobile communications, amateur radio, police, fire and emergency medical services broadcasts, weather radio, CT scan, magnetic resonance imaging, positron emission tomography, ultrasound, cordless phones.
Ultra high frequency	UHF	9	300–3,000 MHz 100–10 cm	Television broadcasts, cable television broadcasting, microwave oven, radars, microwave devices/communications, radio astronomy, radars (L band), mobile phones, wireless LAN, Bluetooth, Zigbee, GPS and two-way radios such as land mobile, emergency locator

				beacon, FRS and GMRS radios, amateur radio, satellite radio, police, fire and emergency medical services broadcasts, remote control systems, ADSB, cordless phones, internet, dial-up internet, satellite broadcasting, communication satellites, weather satellites, satellite phones (L band), satellite phones (S band).
Super high frequency	SHF	10	3–30 GHz 10–1 cm	Radio astronomy, microwave devices/communications, wireless LAN, DSRC, most modern radars, communications satellites, cable and satellite television broadcasting, DBS, amateur radio, satellite broadcasting, communication satellites, weather satellites, satellite radio, cordless phones, internet, satellite phones (S band).
Extremely high frequency	EHF	11	30–300 GHz 10–1 mm	Radio astronomy, satellite broadcasting, communication satellites, weather satellites, high-frequency microwave radio relay, microwave remote sensing, directed-energy weapon, millimeter wave scanner, Wireless Lan 802.11ad, internet.
Terahertz or tremendously high frequency	THF	12	300–3,000 GHz 1–0.1 mm	Experimental medical imaging to replace X-rays, ultrafast molecular dynamics, condensed-matter physics, terahertz time-domain spectroscopy, terahertz computing/communications, remote sensing

IEEE radar bands

Frequency bands in the microwave range are designated by letters. This convention began around World War II with military designations for frequencies used in radar, which was the first application of microwaves. There are several incompatible naming systems for microwave bands, and even within a given system the exact frequency range designated by a letter may vary somewhat between different application areas. One widely used standard is the *IEEE radar bands* established by the US Institute of Electrical and Electronics Engineers.

Radar-frequency bands according to IEEE standard[17]

Band designation	Frequency range	Explanation of meaning of letters
HF	0.003 to 0.03 GHz	High frequency[18]
VHF	0.03 to 0.3 GHz	Very high frequency[18]
UHF	0.3 to 1 GHz	Ultra-high frequency[18]
L	1 to 2 GHz	Long wave
S	2 to 4 GHz	Short wave
C	4 to 8 GHz	Compromise between S and X
X	8 to 12 GHz	Used in World War II for fire control, X for cross (as in crosshair). Exotic.[19]
K_u	12 to 18 GHz	*Kurz*-under
K	18 to 27 GHz	German: *Kurz* (short)
K_a	27 to 40 GHz	*Kurz*-above
V	40 to 75 GHz	
W	75 to 110 GHz	W follows V in the alphabet[20]
mm or G	110 to 300 GHz[note 1]	Millimeter[17]

1. The designation mm is also used to refer to the range from 30 to 300 GHz.[17]

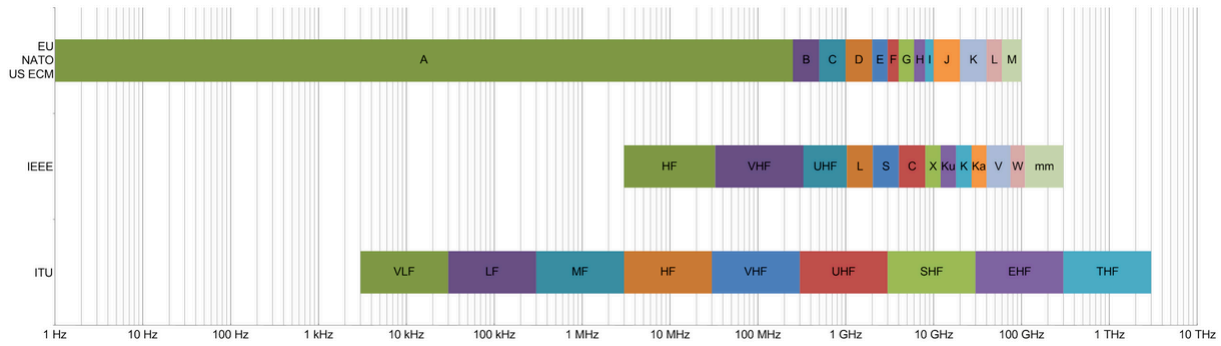
EU, NATO, US ECM frequency designations

NATO letter band designation[21][19][22]				Broadcasting band designation
1978[23]-Present nomenclature		Pre-1978 nomenclature		
Band	Frequency (MHz)	Band	Frequency (MHz)	
A	0 – 250	I	100 – 150	Band I 47 – 68 MHz (TV)
				Band II 87.5 – 108 MHz (FM)
		G	150 – 225	Band III 174 – 230 MHz (TV)
B	250 – 500	P	225 – 390	
C	500 – 1 000	L	390 – 1 550	Band IV 470 – 582 MHz (TV)
				Band V 582 – 862 MHz (TV)
D	1 000 – 2 000	S	1 550 – 3 900	
E	2 000 – 3 000			
F	3 000 – 4 000			
G	4 000 – 6 000	C	3 900 – 6 200	
H	6 000 – 8 000	X	6 200 – 10 900	
I	8 000 – 10 000			
J	10 000 – 20 000	Ku	10 900 – 20 000	
K	20 000 – 40 000	Ka	20 000 – 36 000	
L	40 000 – 60 000	Q	36 000 – 46 000	
		V	46 000 – 56 000	
M	60 000 – 100 000	W	56 000 – 100 000	
US Military/SACLANT				
N	100 000 – 200 000			
O	100 000 – 200 000			

Waveguide frequency bands

Band	Frequency range [24]
R band	1.70 to 2.60 GHz
D band	2.20 to 3.30 GHz
S band	2.60 to 3.95 GHz
E band	3.30 to 4.90 GHz
G band	3.95 to 5.85 GHz
F band	4.90 to 7.05 GHz
C band	5.85 to 8.20 GHz
H band	7.05 to 10.10 GHz
X band	8.2 to 12.4 GHz
K_u band	12.4 to 18.0 GHz
K band	18.0 to 26.5 GHz
K_a band	26.5 to 40.0 GHz
Q band	33 to 50 GHz
U band	40 to 60 GHz
V band	50 to 75 GHz
E band	60 to 90 GHz
W band	75 to 110 GHz
F band	90 to 140 GHz
D band	110 to 170 GHz
Y band	325 to 500 GHz

Comparison of radio band designation standards



Comparison of frequency band designations

A frequency of 1–3 Hz[15] has been called TLF but the term has not been defined by the ITU.[25]

Frequency	IEEE[17]	EU, NATO, US ECM	ITU	
			no.	abbr.
3 Hz		A		
			1	ELF
30 Hz			2	SLF
300 Hz			3	ULF
3 kHz			4	VLF
30 kHz			5	LF
300 kHz			6	MF
3 MHz	HF		7	HF
30 MHz				
250 MHz	VHF		8	VHF
300 MHz		B		
500 MHz	UHF		9	UHF
1 GHz		C		
2 GHz	L	D		
3 GHz	S	E		
		F	10	SHF
4 GHz		G		
6 GHz	C			
8 GHz		H		
10 GHz	X	I		
12 GHz		J		
18 GHz	K_u			
20 GHz	K			
27 GHz		K		
30 GHz	K_a			
40 GHz		L		
60 GHz	V			
75 GHz		M	11	EHF
100 GHz	W			
110 GHz				
300 GHz	mm			
			12	THF
3 THz				

Applications

Broadcasting

Broadcast frequencies:

- Longwave AM Radio = 148.5 kHz – 283.5 kHz (LF)
- Mediumwave AM Radio = 520 kHz – 1700 kHz (MF)
- Shortwave AM Radio = 3 MHz – 30 MHz (HF)

Designations for television and FM radio broadcast frequencies vary between countries, see Television channel frequencies and FM broadcast band. Since VHF and UHF frequencies are desirable for many uses in urban areas, in North America some parts of the former television broadcasting band have been reassigned to cellular phone and various land mobile communications systems. Even within the allocation still dedicated to television, TV-band devices use channels without local broadcasters.

The Apex band in the United States was a pre-WWII allocation for VHF audio broadcasting; it was made obsolete after the introduction of FM broadcasting.

Air band

Airband refers to VHF frequencies 108 to 137 MHz, used for navigation and voice communication with aircraft. Trans-oceanic aircraft also carry HF radio and satellite transceivers.

Marine band

The greatest incentive for development of radio was the need to communicate with ships out of visual range of shore. From the very early days of radio, large oceangoing vessels carried powerful long-wave and medium-wave transmitters. High-frequency allocations are still designated for ships, although satellite systems have taken over some of the safety applications previously served by 500 kHz and other frequencies. 2182 kHz is a medium-wave frequency still used for marine emergency communication.

Marine VHF radio is used in coastal waters and relatively short-range communication between vessels and to shore stations. Radios are channelized, with different channels used for different purposes; marine Channel 16 is used for calling and emergencies.

Amateur radio frequencies

Amateur radio frequency allocations vary around the world. Several bands are common for amateurs worldwide, usually in the HF part of the spectrum. Other bands are national or regional allocations only due to differing allocations for other services, especially in the VHF and UHF parts of the radio spectrum.

Citizens' band and personal radio services

Citizens' band radio is allocated in many countries, using channelized radios in the upper HF part of the spectrum (around 27 MHz). It is used for personal, small business and hobby purposes. Other frequency allocations are used for similar services in different jurisdictions, for example UHF CB is allocated in Australia. A wide range of personal radio services exist around the world, usually emphasizing short-range communication between individuals or for small businesses, simplified license requirements or in some countries covered by a class license, and usually FM transceivers using around 1 watt or less.

Industrial, scientific, medical

The ISM bands were initially reserved for non-communications uses of RF energy, such as microwave ovens, radio-frequency heating, and similar purposes. However, in recent years the largest use of these bands has been by short-range low-power communications systems, since users do not have to hold a radio operator's license. Cordless telephones, wireless computer networks, Bluetooth devices, and garage door openers all use the ISM bands. ISM devices do not have regulatory protection against interference from other users of the band.

Land mobile bands

Bands of frequencies, especially in the VHF and UHF parts of the spectrum, are allocated for communication between fixed base stations and land mobile vehicle-mounted or portable transceivers. In the United States these services are informally known as business band radio. See also Professional mobile radio.

Police radio and other public safety services such as fire departments and ambulances are generally found in the VHF and UHF parts of the spectrum. Trunking systems are often used to make most efficient use of the limited number of frequencies available.

The demand for mobile telephone service has led to large blocks of radio spectrum allocated to

cellular frequencies.

Radio control

Reliable radio control uses bands dedicated to the purpose. Radio-controlled toys may use portions of unlicensed spectrum in the 27 MHz or 49 MHz bands, but more costly aircraft, boat, or land vehicle models use dedicated radio control frequencies near 72 MHz to avoid interference by unlicensed uses. The 21st century has seen a move to 2.4 GHz spread spectrum RC control systems.

Licensed amateur radio operators use portions of the 6-meter band in North America. Industrial remote control of cranes or railway locomotives use assigned frequencies that vary by area.

Radar

Radar applications use relatively high power pulse transmitters and sensitive receivers, so radar is operated on bands not used for other purposes. Most radar bands are in the microwave part of the spectrum, although certain important applications for meteorology make use of powerful transmitters in the UHF band.

See also

- AM broadcasting
- Amateur radio frequency allocations
- Bandstacked
- Broadcasting
- Cellular frequencies
- Copenhagen Frequency Plan of 1948
- DXing
- FM broadcast band
- Frequency allocation
- Geneva Frequency Plan of 1975
- Ham radio
- North American Regional Broadcasting Agreement

- Open spectrum
- Orbit spectrum
- Radio astronomy
- Radio broadcasting
- Radio communication
- Scanner (radio)
- Two-way radio
- U-NII
- Ultra-wideband
- WARC bands

Notes

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External links

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